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HYDROLOGIC DESIGN OF SMALL FARM PONDS IN THE CLAYPAN PRAIRIES OF MISSOURI

Based on SCS-TP-56, "Hydrologic Design of Farm Ponds and Rates of Runoff for Design of Conservation Structures in the Claypan Prairies," May, 1945

By

D. B. Krimgold and N. E. Minshall

Division of Drainage and Water Control

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HYDROLOGIC DESIGN OF SMALL FARM PONDS

For a number of years Soil Conservation Service Research in co-operation with several State Agricultural Experiment Stations has carried on runoff studies applicable to the Claypan Prairies of Missouri.

An analysis of records for 6 years has been made and the results are given in *(SCS-TP-56)* entitled "Hydrologic Design of Farm Ponds and Rates of Runoff for Design of Conservation Structures in the Claypan Prairies" by D. B. Krimgold and N. E. Minshall.

The following discussion outlines a simplified procedure for the design of small ponds in the Claypan Prairies of Missouri for use of technicians engaged in such work and gives rates of runoff for the design of conservation structures. The procedure is based on certain assumptions and its use should be limited to small ponds where the amount of water to be used per year will not exceed 1 acre-foot (about 326,000 gals.) and where the cost will not exceed $500. The procedure outlined in *SCS-TP-56* should be followed in designing larger ponds.

The great majority of small farm ponds are neither entirely in excavation nor entirely natural. The actual condition existing in most cases is illustrated in *figure 2*. The excavated portion V_2 represented by the shaded area in the sketch usually represents an appreciable portion of the total volume. When the borrow pit for the dam or dike is off the pond area, there is no excavation and the entire volume of the pond is above the original natural ground. Only when the site is level or practically level can the volume above the natural ground V_1 be neglected.

Table 1 gives values of a factor K for converting surface area at 5 feet above natural ground to total volumes at various elevations h above natural ground. This relation is based upon a study of a large number of ponds made by W. D. Potter of the Division of Drainage and Water Control, and verified by the authors.

Table 2 shows drainage areas in pasture or in mixed crops required to furnish a dependable supply of water for small ponds in the Claypan Prairies of Missouri. The values in *table 2* apply only to the counties and parts of counties indicated in *figure 1*. In the Claypan Prairies it is neither necessary nor advisable to use clean cultivated drainage areas for farm ponds. Using such areas will result in excessive runoff detrimental to the grassed spillways commonly used.

Rates of runoff to be used in determining the required capacity of spillways are given in *figure 3*. The design of the spillway for the required capacity should follow existing recommendations and instructions.

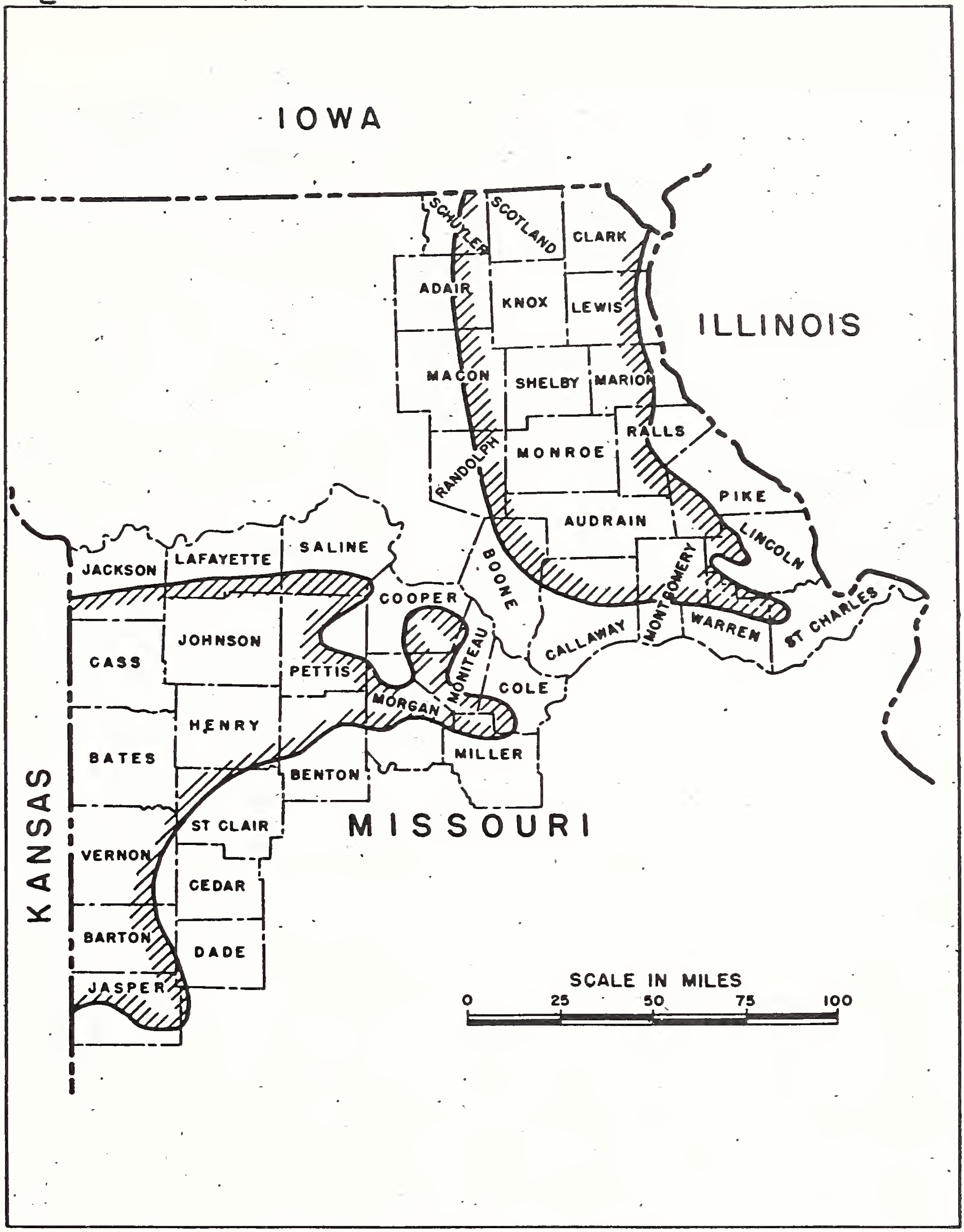

Figure I.—Claypan Prairies in Missouri

TABLE 1.—*Factor K for converting surface area at 5 feet above natural ground to total volumes at various elevations h above natural ground*

h	*K*	*h*	*K*
feet		*feet*	
1	0.04	9	9.18
2	.25	10	11.80
3	.65	11	15.50
4	1.22	12	19.40
5	2.13	13	24.20
6	3.17	14	29.40
7	4.76	15	35.60
8	6.66		

Legend for sketch

V_1 = Volume above natural ground

V_2 = Volume of excavation

For ponds wholly in excavation the bottom of the spillway is at or below natural ground and *h* and V_1 = 0

For natural ponds with borrow pits off the pond sites V_2 = 0 and *h* = *D*

TABLE 2.—*Drainage areas required to furnish a dependable supply of water in small farm ponds*

Volume at Spillway Elevation ($V_1 + V_2$)		Drainage area required for ponds with depths *D* =			
		6-8 ft.	8-10 ft	10-12 ft	12-15 ft
ac.-ft.	*cu. yds.*	*acres*	*acres*	*acres*	*acres*
0.6	970	4.7	4.6	4.5	4.5
.7	1,130	5.0	4.9	4.8	4.7
.8	1,290	5.2	5.1	5.0	5.0
.9	1,455	5.5	5.3	5.3	5.2
1.0	1,615	5.8	5.6	5.5	5.4
1.1	1,775	6.1	5.9	5.8	5.7
1.2	1,935	6.3	6.1	6.0	5.9
1.3	2,100	6.6	6.4	6.2	6.2
1.4	2,260	6.9	6.6	6.5	6.4
1.5	2,420	7.2	6.9	6.7	6.6
1.6	2,580	7.4	7.2	7.0	6.9
1.7	2,745	7.7	7.4	7.2	7.1
1.8	2,905	8.0	7.7	7.5	7.3
1.9	3,065	8.2	7.9	7.7	7.6
2.0	3,230	8.5	8.2	8.0	7.8
2.1	3,390	8.8	8.4	8.2	8.1
2.2	3,550	9.1	8.7	8.4	8.3
2.3	3,710	9.3	9.0	8.7	8.6
2.4	3,875	9.6	9.2	8.9	8.8
2.5	4,035	9.9	9.4	9.2	9.0
2.6	4,195	10.1	9.7	9.5	9.3
2.7	4,360	10.4	10.0	9.7	9.5
2.8	4,520	10.7	10.2	9.9	9.7
2.9	4,680	11.0	10.5	10.2	10.0
3.0	4,840	11.3	10.8	10.4	10.2

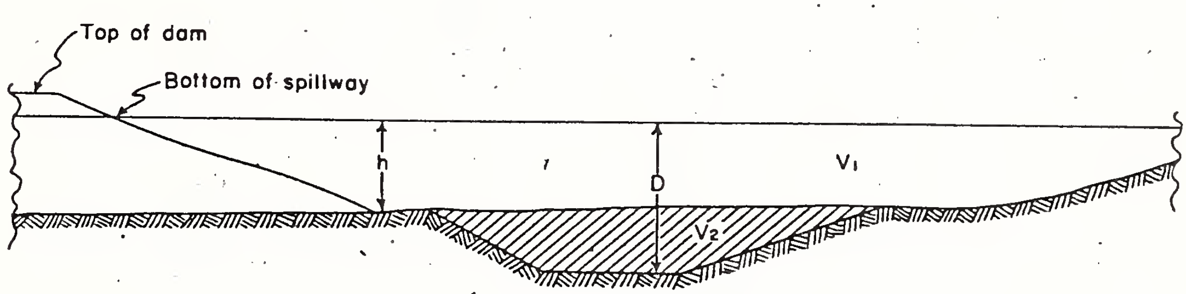

FIGURE 2.—Sketch of a small farm pond

When excavation is involved and particularly when the pond is wholly or nearly wholly in excavation, it is necessary to determine the top dimensions which with a given side slope and depth will result in a given volume.

Small excavated ponds are approximately circular or rectangular in shape and are usually constructed with 3:1 side slopes. For excavations with 3:1 side slopes, top diameters for circular ponds and top widths for rectangular ponds in which the length is 1.5 times the width are given in *table 3*.

For other side slopes and other ratios of length to width, the top dimensions can be computed by the following formulas:

For circular ponds:-

$$\text{Top Diameter} = SD + \sqrt{34.36\frac{V}{D} - \frac{(SD)^2}{3}} \qquad (1)$$

For rectangular ponds:-

$$\text{Top Width} = \frac{(SD + SDF) + \sqrt{(SD + SDF)^2 - 4F\left[\frac{4}{3}(SD)^2 - \frac{27V}{D}\right]}}{2F} \qquad (2)$$

In the above formulas:

S is the side slope of excavation ($S = 3$ for 3:1; 2 for 2:1, etc.)

D is the depth of the excavation in feet

V is the volume of excavation in cubic yards

F is the ratio $\frac{\text{length}}{\text{width}}$ for rectangular ponds

TABLE 3.—*Top dimensions in feet of excavated circular and rectangular ponds with 3:1 side slopes for various volumes and depths.*

Volume, of Excavation	Depths 3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.
cu. yards	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*
				Top Diameters of Circular Ponds				
200	56.5	52.9	51.1	50.2	*	*	*	*
300	67.0	61.5	58.8	57.3	56.8	56.5	*	*
400	76.4	70.2	66.7	64.7	63.7	63.1	*	*
500	84.3	76.8	72.5	70.0	69.0	68.0	67.6	67.3
600	91.7	83.4	78.6	75.7	73.9	72.8	72.3	71.9
700	98.3	89.0	83.8	80.2	78.0	76.9	76.2	75.6
800	104.5	94.6	88.6	84.9	82.5	81.0	80.0	79.2
900	110.0	99.6	93.3	89.0	86.2	84.7	83.6	82.8
1,000	115.6	104.2	97.7	93.0	90.0	88.0	86.8	86.0
1,100	121.0	108.9	101.7	96.7	93.2	91.2	90.0	89.0
1,200	126.0	113.5	105.4	100.3	96.8	94.5	92.9	91.9
1,300	130.6	117.2	109.2	103.5	99.8	97.5	95.9	94.6
1,400	135.0	121.1	112.8	107.0	103.0	100.3	98.5	97.2
1,500	139.7	125.0	116.1	110.0	105.8	103.0	101.0	99.8
1,600	144.3	129.0	119.4	113.2	108.8	105.8	103.6	102.1
1,700	148.0	132.1	122.9	116.0	111.2	108.4	106.0	104.3
1,800	152.1	135.7	126.0	119.0	114.2	110.9	108.2	106.8
1,900	156.2	139.0	129.0	121.8	116.7	113.2	110.4	108.7
2,000	160.3	142.8	132.0	124.5	119.0	115.7	112.8	110.9
2,100	164.0	146.0	135.0	127.0	121.8	118.0	114.9	112.9
2,200	167.7	149.2	137.9	129.7	124.1	120.0	117.0	115.0
2,300	171.0	152.5	140.5	132.0	126.6	122.3	118.9	117.0
2,400	174.8	155.5	143.1	134.6	128.9	124.6	121.0	118.9
2,500	178.0	158.6	145.7	137.0	131.1	126.5	122.9	120.8
2,600	181.3	161.3	148.4	139.0	133.2	128.4	125.0	122.8
2,700	184.4	164.1	150.8	141.5	135.4	130.7	127.0	124.6
2,800	187.[illegible]	166.9	153.6	144.0	137.6	132.8	129.0	126.6
2,900	190.[illegible]	169.3	155.7	146.0	139.6	134.8	130.9	128.2
3,000	194.2	172.3	158.2	148.7	141.8	136.7	132.9	130.0
			Top Widths of Rectangular Ponds with Lengths = 1.5 the widths					
200	41.8	39.5	38.5	*	*	*	*	*
300	49.6	46.3	44.4	43.5	*	*	*	*
400	56.3	52.2	49.9	48.8	48.2	*	*	*
500	62.3	57.1	54.1	52.7	51.9	*	*	*
600	67.3	61.7	58.5	56.7	55.7	55.2	*	*
700	72.5	66.0	62.3	60.4	58.8	58.2	*	*
800	76.6	69.7	65.8	63.3	61.9	61.1	*	*
900	81.0	73.6	69.0	66.5	64.5	63.6	63.2	*
1,000	84.9	77.0	72.1	69.2	67.4	66.2	65.6	*
1,100	88.5	80.1	75.0	72.0	69.9	68.8	68.0	67.5
1,200	92.2	83.3	77.9	74.6	72.2	71.0	70.0	69.5
1,300	95.5	86.1	80.5	77.0	74.5	73.1	72.1	71.5
1,400	98.8	89.0	83.0	79.5	76.8	75.2	74.0	73.3
1,500	102.0	91.7	85.4	81.6	78.9	77.1	76.0	75.2
1,600	105.4	94.7	88.1	84.0	81.0	79.1	77.8	77.0
1,700	108.2	96.9	90.1	86.0	82.8	81.0	79.6	78.7
1,800	111.0	99.4	92.4	88.0	84.8	82.8	81.2	80.2
1,900	113.9	101.8	94.6	90.0	86.6	84.5	82.9	82.0
2,000	117.0	104.7	97.1	92.1	88.6	86.2	84.6	83.5
2,100	119.4	106.5	98.8	94.0	90.2	87.9	86.0	85.0
2,200	122.0	108.8	100.9	95.8	92.0	89.5	87.6	86.4
2,300	124.7	111.0	102.9	97.5	93.8	91.0	89.1	88.0
2,400	127.5	113.9	105.2	99.4	95.5	92.6	90.7	89.4
2,500	130.0	115.4	106.8	101.2	97.1	94.2	92.2	90.8
2,600	132.4	118.2	109.0	102.8	98.7	95.8	93.7	92.2
2,700	134.8	119.8	110.5	104.5	100.3	97.2	95.0	93.6
2,800	137.1	122.2	112.5	106.2	101.8	98.7	96.4	94.9
2,900	139.4	124.3	114.8	107.8	103.2	100.0	97.8	96.1
3,000	141.7	126.2	116.4	109.5	104.5	101.5	99.0	97.3

* impossible or impractical to excavate with 3:1 or flatter side slopes

The various steps in the hydrologic design of a small farm pond are as follows:

STEP 1. Examine the proposed site to determine whether it can be expected to hold water and whether the material is suitable for a dam or dike. Make borings if in doubt. Sealing with clay or bentonite or the use of a borrow pit away from the site may be considered if economically feasible.

STEP 2. With a map, aerial photograph, or by actual survey determine the drainage area above the selected site to the nearest 0.1 acre.

STEP 3. With a transit, an engineer's level, or a hand level, and by pacing, determine the surface area at 5 feet above the low spot of the natural ground at the site of the proposed dam or dike.

STEP 4. With the drainage area determined in step 2, obtain rate of runoff from *figure 3*. Design spillway for this rate and determine elevation of bottom of the spillway above low spot in natural ground. This is h in *figure 2*.

STEP 5. Obtain V_1 the volume above natural ground in acre-feet by multiplying the value obtained in step 3 by the factor K *(from table 1)* corresponding to the value of h obtained in step 4.

Note: Omit steps 3, 4, and 5 if pond is entirely in excavation.

STEP 6. The volume of excavation V_2 is usually determined by available funds. Divide the volumes of excavation in cubic yards by 1,614 (to convert to ac.-ft.) and add to the volume V_1 obtained in step 5 to obtain total volume of pond in acre-feet.

Note: If fill is from an off-site borrow pit, the volume of excavation V_2 will be zero.

STEP 7. With the volume obtained in step 6 $(V_1 + V_2)$, find in *table 2* the total depth D corresponding to the available drainage area determined in step 2.

STEP 8. Determine the depth of excavation by subtracting the value of h as determined in step 4 from D obtained in step 7.

STEP 9. With the volume of excavation V_2 and the depth of excavation determined in step 8, obtain the top dimensions of excavation from *table 3* (directly or by interpolation) or from formulas (1) or (2).

Note: If the drainage area is too large or too small, reduce it or increase it by diverting the proper acreage from or into the drainage area or try a smaller or larger value of h and repeat steps 4, 5, 6, and 7. Make sure the area adjoining the pond is amply protected with grass to prevent silting of the pond.

The following examples will illustrate the use of this procedure:

EXAMPLE 1

Given (a) Drainage area of 6.5 acres of moderately grazed pasture

(b) Total excavation 750 cubic yards from borrow pit on pond site.

(c) Bottom of spillway 8 feet above the bottom of natural ground (h = 8)

(d) Surface area at 5 feet above natural ground = 0.2 acre. K from *table 1* is 6.66 for h = 8 feet

Solution:

Volume of pond above natural ground = 0.2K = 0.2 x 6.66 = 1.33 acre-feet

Total volume of pond equals

$$1.33 + \frac{750}{1{,}614} = 1.33 + 0.47 = 1.8 \text{ acre-feet}$$

Table 2 shows that the minimum required area is 7.3 acres and the total depth D must not be less than 12 feet.

This pond will therefore furnish a dependable supply only if 0.8 acre is added to the drainage area by diversion and if the bottom of the completed pond is not less than 12 feet below the bottom of the spillway.

If diversion is not practical, the spillway may be lowered to reduce the total volume.

Try h = 7 feet then K = 4.76.

Volume above natural ground = 0.2 x 4.76 = 0.95 acre-foot. Volume of excavation required for h = 7 is estimated to be 80 percent of that for h = 8 or about 0.38 acre-foot (615 cu. yds.) and total volume of the pond = 0.95 + 0.38 = 1.33 or 1.3 acre-feet.

Table 2 shows that with a total volume of 1.3 acre-feet a dependable supply can be obtained with a 6.4-acre drainage area (which is within 0.1 acre of the available 6.5 acres) if the bottom of the completed pond is not less than 8 feet below the bottom of the spillway.

The depth of excavation for the total volume of 615 cubic yards must therefore not be less than 1 foot (8 - 7).

It will probably not be practical to excavate to a depth less than 3 feet. If the ground where the excavation is to be made does not slope too steeply and if the side slopes are to be 3:1, the top dimensions of the excavation can be obtained from *table 3*. For an excavation of 615 cubic yards, this table (by interpolation) gives the following:

Top diameter of a circular excavation = 92.7 for a depth of 3 feet; 84.2 feet for a depth of 4 feet; and 79.5 for a depth of 5 feet.

Top width of a rectangular excavation with a length to width ratio of 1.5 = 68.1, 62.3, and 59.1 feet for depths of excavation of 3, 4, and 5 feet respectively. The depth of excavation giving suitable top dimensions for the site should be used.

EXAMPLE 2

Given (a) Drainage area of 9.0 acres

(b) Funds sufficient to build a dam with a spillway 12 feet above natural ground (h = 12 ft.)

(c) Borrow pit off the pond site

(d) Surface area at 5 feet above natural ground = 0.2 acre. From *table 1*, K for 12 feet = 19.4

Solution:

Volume of pond above natural ground = 19.4 x 0.2 = 3.88 acre-feet.

Volume of excavation is zero and $h = D$ in this case.

The total volume of this pond with D = 12 feet exceeds 3 acre-feet and can therefore not be designed by this procedure.

Try h = 10 feet (bottom of spillway 10 ft. above natural ground), then K = 11.8 and total volume = 11.8 x 0.2 = 2.36 or 2.4 acre-feet.

Table 2 shows a drainage area of 8.9 acres which is within 0.1 acre of the available area. The pond will therefore be satisfactory if the bottom of the spillway is not less than 10 feet above the bottom of the reservoir.

EXAMPLE 3

Given (a) A 1,200 cubic-yard pond is to be excavated on a nearly level site.

(b) Runoff from a required acreage of pasture will be diverted into the excavated pond by means of a diversion ditch.

(c) Excavated material will be piled in spoil banks and the spillway will be at elevation of natural ground.

Solution:

Volume above natural ground $V_1 = 0$

Total volume = $\frac{1,200}{1,614}$ = 0.74 acre-foot

For depth 6 to 8 feet, *table 2* gives drainage area of 5.0 acres for 0.7 acre-foot and 5.2 acres for 0.8 acre-foot. The drainage area should therefore be 5.1 acres and the total depth D not less than 6 feet.

If the side slopes of the excavation are 3:1, the top dimensions of the excavation can be obtained from *table 3*.

For 1,200 cubic yards and a 6-foot depth, the top diameter of a circular pond would be 100.3 feet and the top width of a rectangular pond with a length to width ratio of 1.5 would be 74.6 feet.

RATES OF RUNOFF

Rates of runoff which can be expected to be equaled or exceeded on the average once in 25 years are given in *figures 3 and 4*.

The 2 curves in *figure 3* are for drainage areas up to 100 acres in size. One of these curves is for terraced and unterraced drainage areas either entirely in row crops or in mixed cover which included pasture, woodlots, and cultivated lands, while the other applies to areas entirely in pasture. These curves are to be used in obtaining rates of runoff for the design of spillways on small farm ponds and of other structures and channels on drainage areas less than 100 acres.

In the Claypan Prairies, drainage areas in excess of 100 acres are rarely in one cover. The curve in *figure 4* gives rates of runoff from drainage areas with mixed cover ranging in size from 100 to 1,600 acres. The runoff rates given in *figure 4* are also for a 25-year expectancy, that is, they can be expected to be equaled or exceeded once in 25 years. Costly structures on large drainage areas and structures whose failure may result in extensive damages are usually designed for expectancies of once in 50 years. To obtain 50-year rates of runoff add 10 percent to rates of runoff given in *figure 4*.

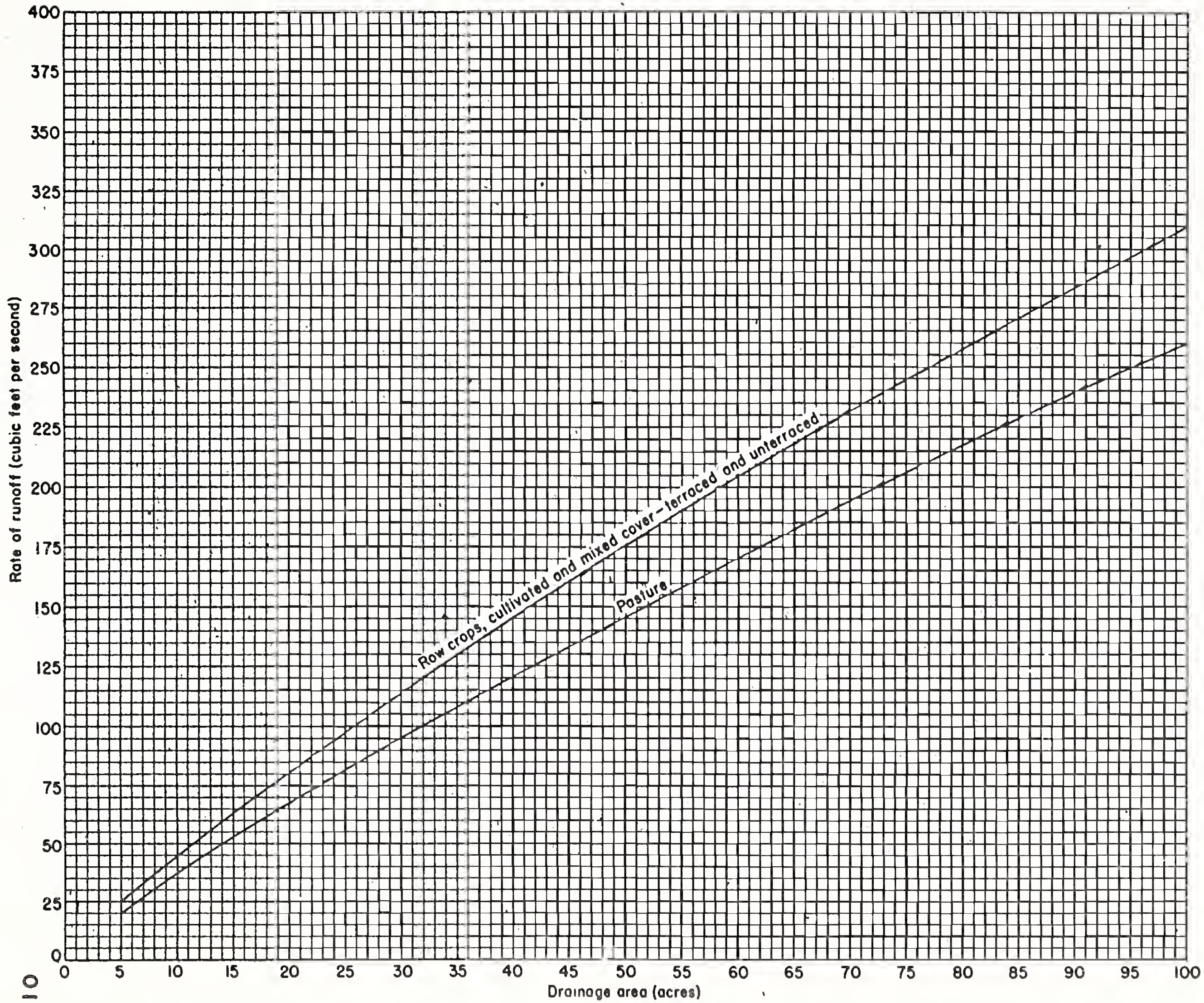

Figure 3.—Rates of runoff for the design of conservation structures in the Claypan Prairies of Missouri on drainage areas up to 100 acres

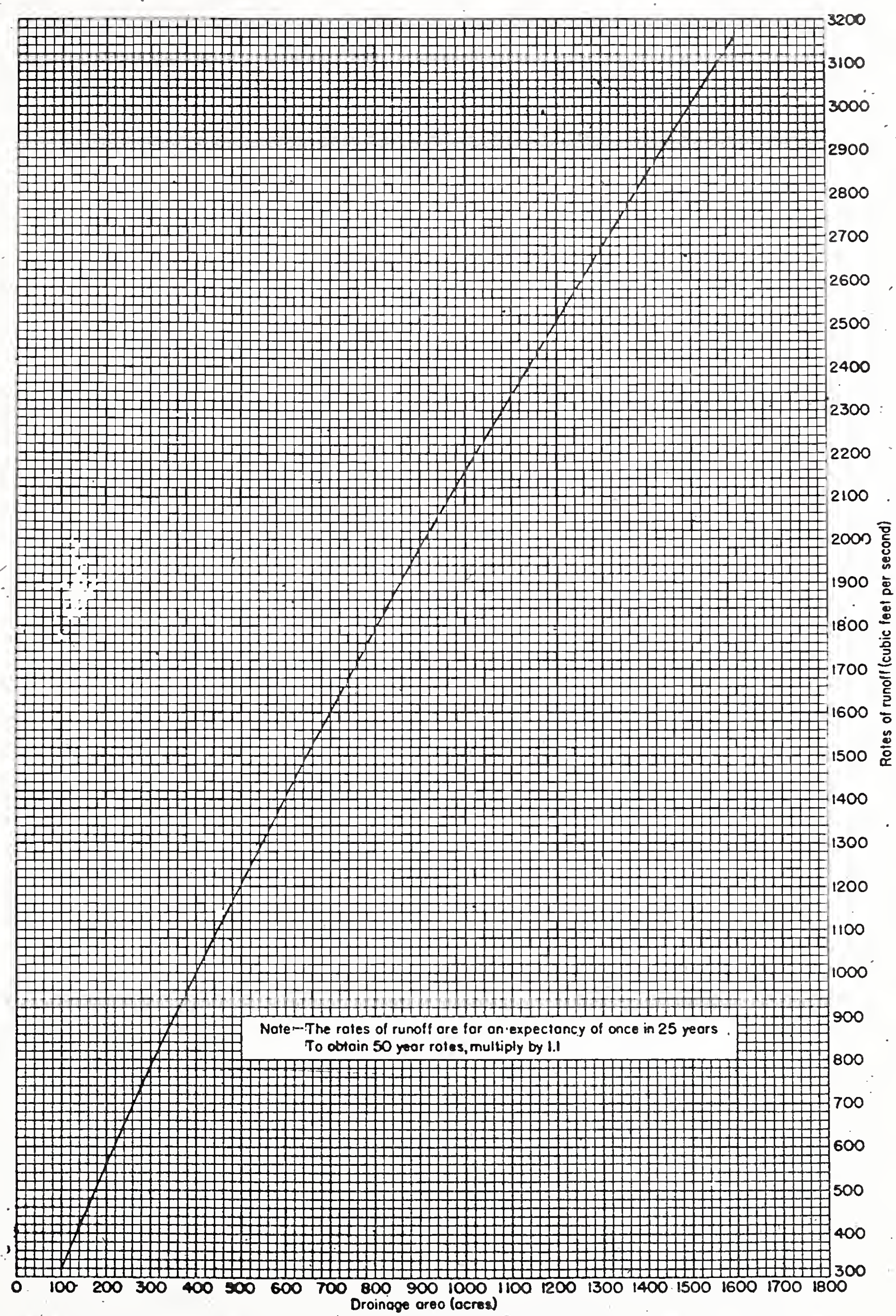

Figure 4.—Rates of runoff for the design of conservation structures in the Claypan Prairies of Missouri on drainage areas in Mixed Cover ranging in size from 100 to 1600 acres